

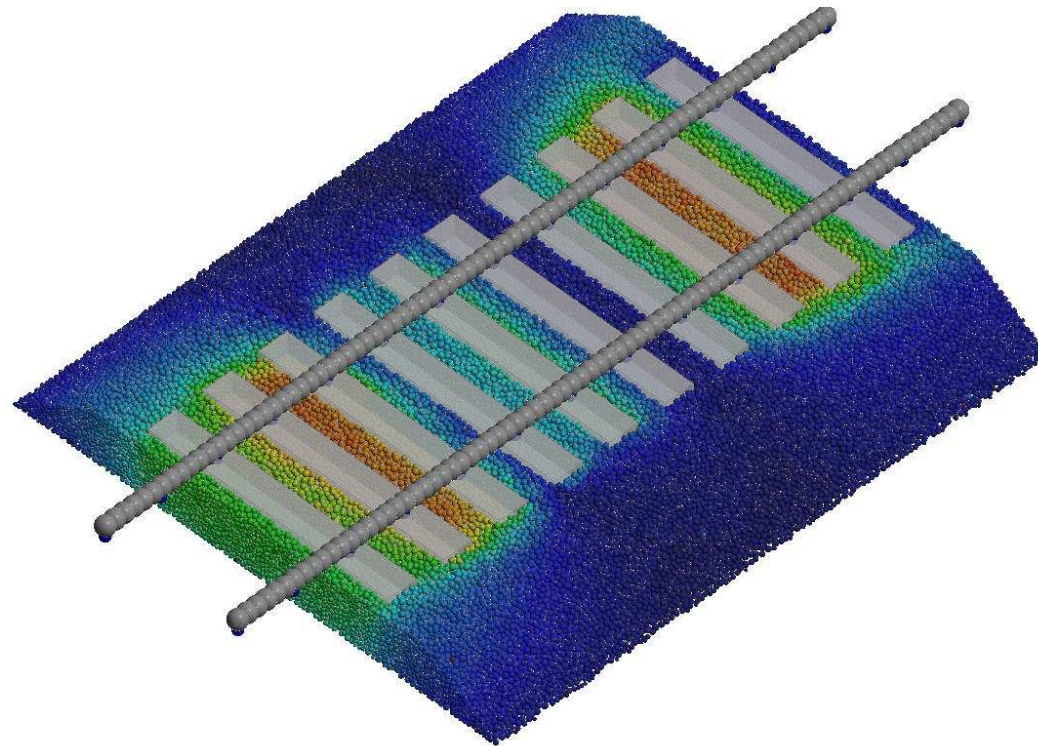


The Fourth International Conference on Railway Technology

RAILWAYS 2018

3–7 September 2018
Sitges, Barcelona, Spain

Advances in the modelling of railway ballast using the Discrete Element Method (DEM)





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1. Introduction to the Discrete Element Method (DEM)
2. Railway ballast modelling within the DEM
3. Calibration and validation tests

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4. Full scale railway track tests under dynamic loads
5. Conclusions and ongoing work

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Introduction to the DEM – Railway ballast

Layer of granular material placed under the sleepers whose roles are resisting to vertical and horizontal loads and facing climate action

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Introduction to the DEM – Force Evaluation

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Force balance

$$m_i \ddot{\mathbf{u}}_i = \mathbf{F}_i^{ext} + \sum_{j=1}^{n_i^c} \mathbf{F}^{ij}$$

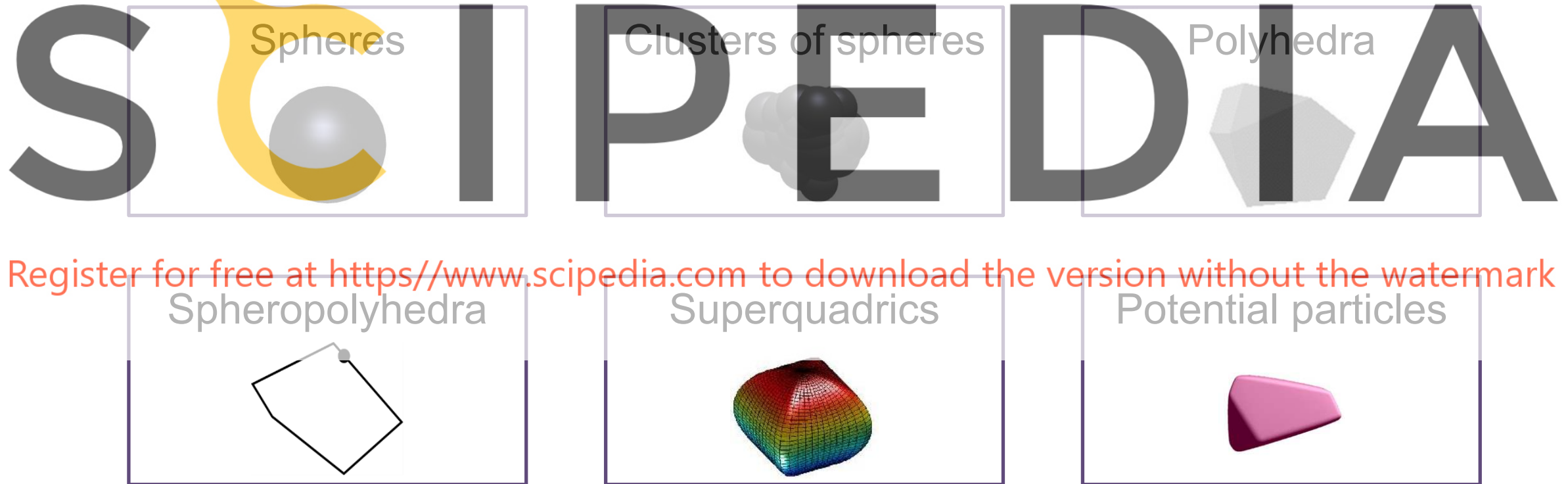
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Torque balance

$$\mathbf{I}_i \dot{\boldsymbol{\omega}}_i = \mathbf{T}_i^{ext} + \sum_{j=1}^{n_i^c} \mathbf{r}_c^{ij} \times \mathbf{F}^{ij}$$

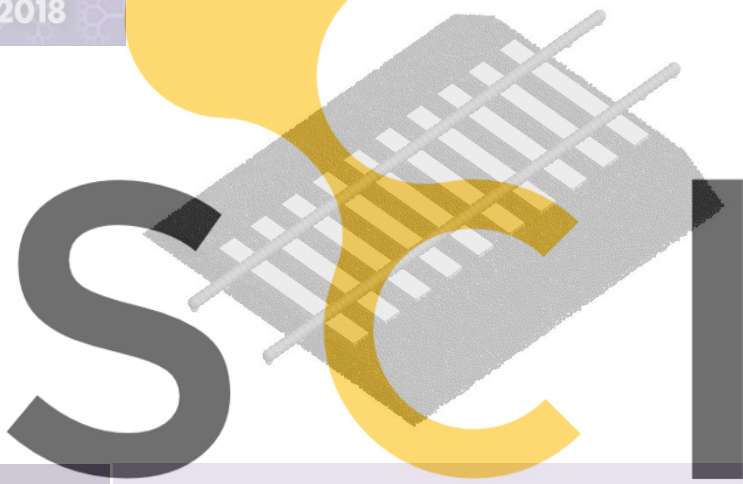


Introduction to the DEM – Geometrical Approaches



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Introduction to the DEM – Geometrical Approaches



Analysed approaches						
Spheres	Sphere clusters	Squad.	Polyhed.	Sphero-Polyhed.	Potential Particles	
✓	x	x	x	x	x	
✓	✓	x	x	✓	x	
x	✓	✓	✓	✓	✓	✓
x	✓	x	✓*	✓*	x	
x	✓	✓*	✓	✓	✓	✓

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Introduction to the DEM – Software



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<http://www.cimne.com/dempack/>

<http://www.cimne.com/kratos/>

<http://gid.cimne.upc.es/>

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1. Introduction to the DEM | 2. Railway ballast modelling within the DEM | 3. Calibration and validation tests | 4. Full scale tests | 5. Conclusions and ongoing work

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Ballast properties

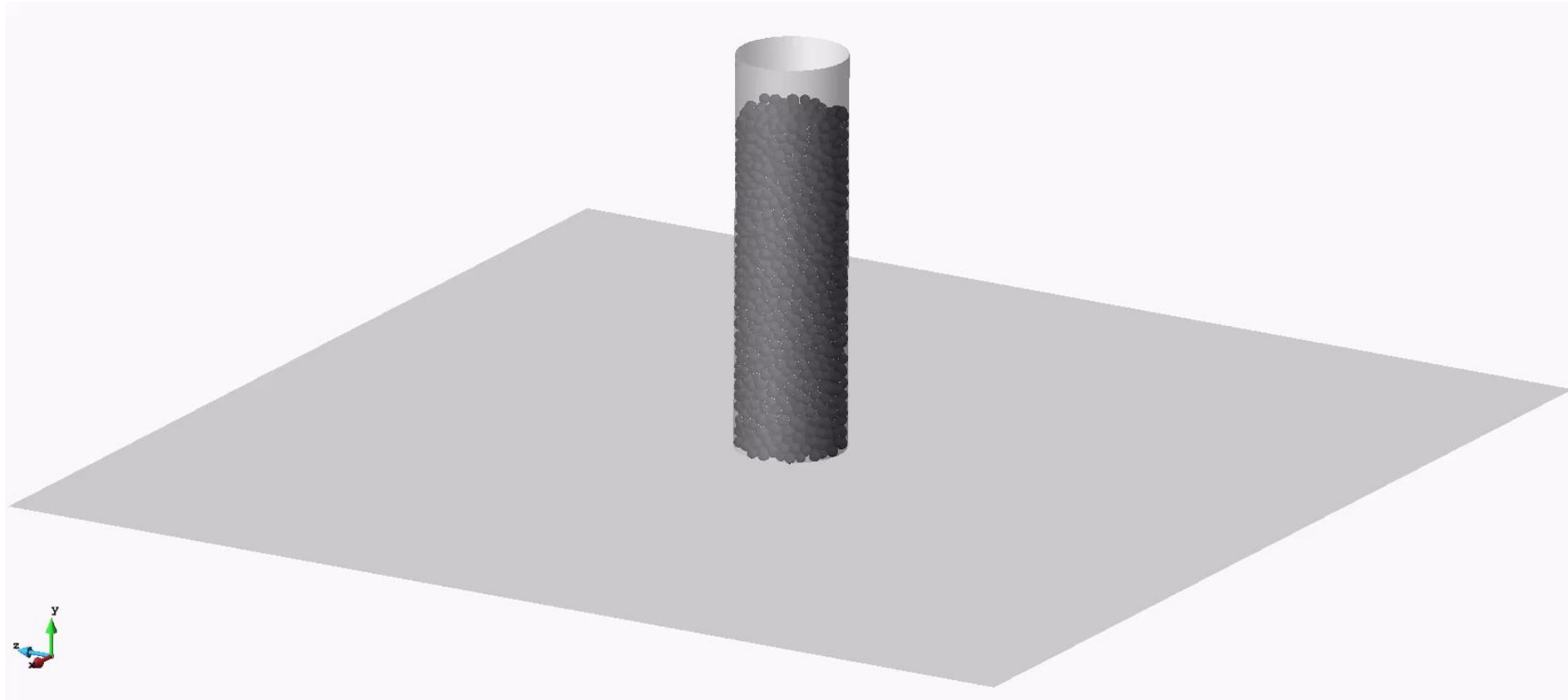
- Density
- Sample size distribution
- The inter-particle friction
- Particle-wall friction
- The initial void ratio
- Coefficient of restitution

Normally well-known

- Particle shape
- Particle stiffness

Some considerations to be taken into account

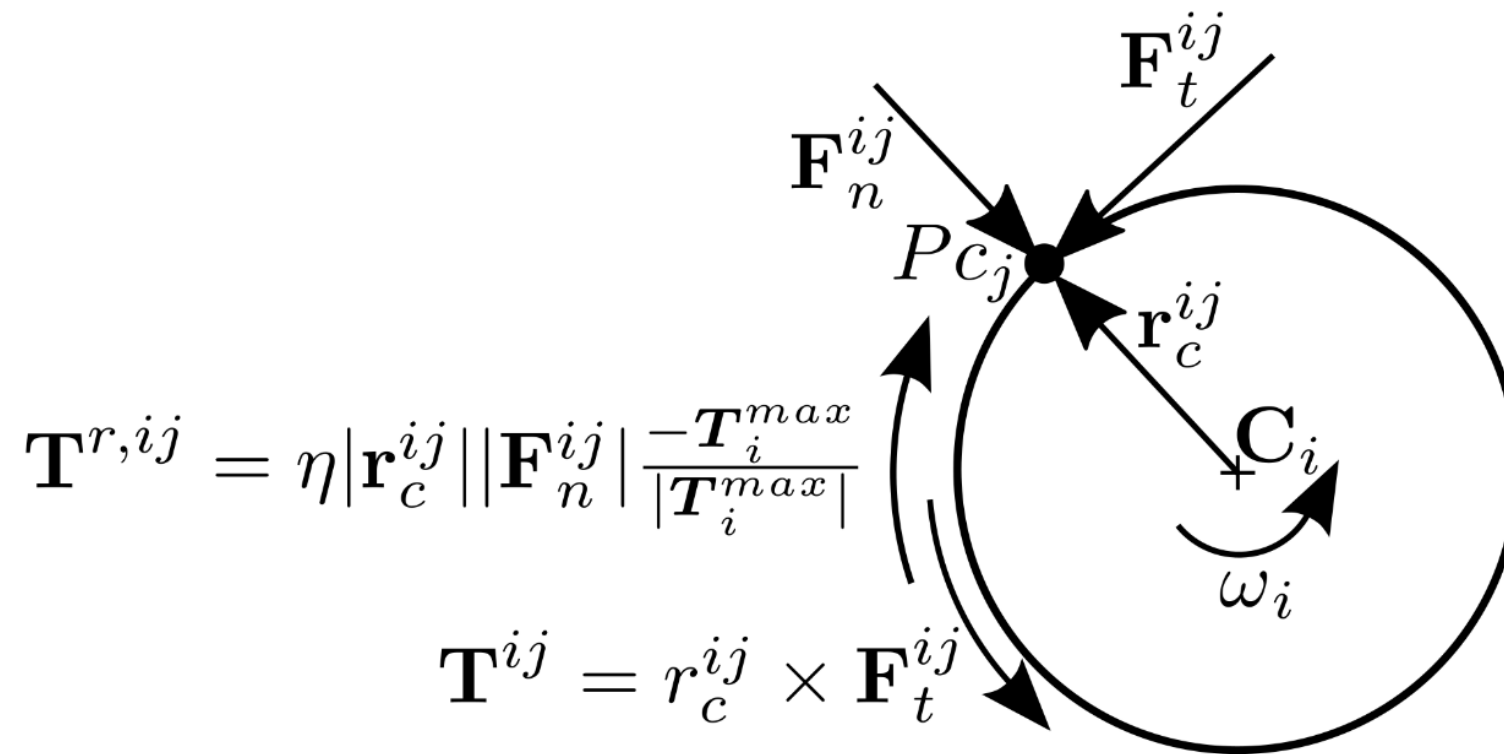
Ballast properties – Particle shape



To avoid excessive particle rotation → Rolling friction

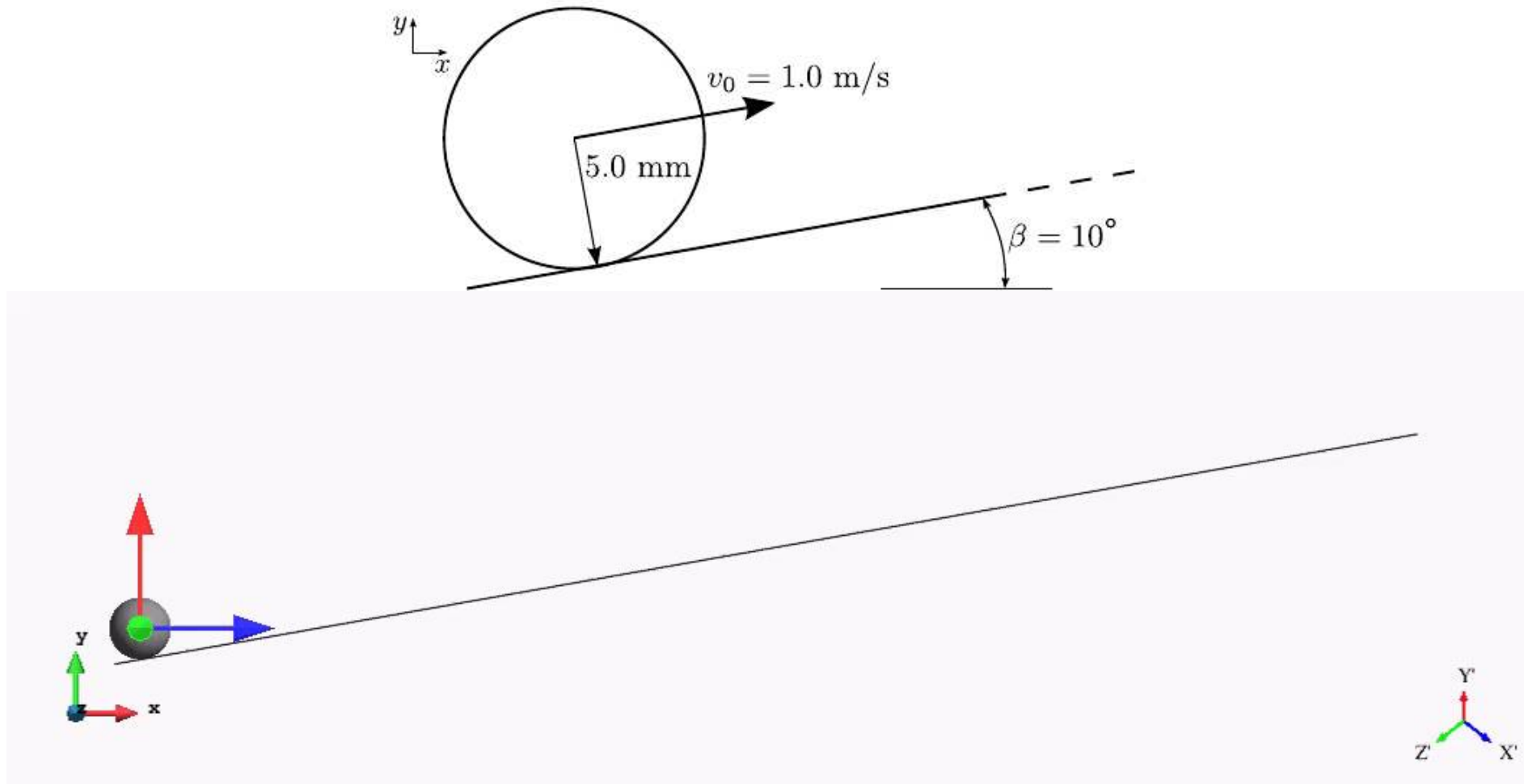
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Ballast properties – Particle shape



Irazábal, J., Salazar, F., & Oñate, E. (2017). Numerical modelling of granular materials with spherical discrete particles and the bounded rolling friction model. Application to railway ballast. Computers and Geotechnics, 85, 220-229.

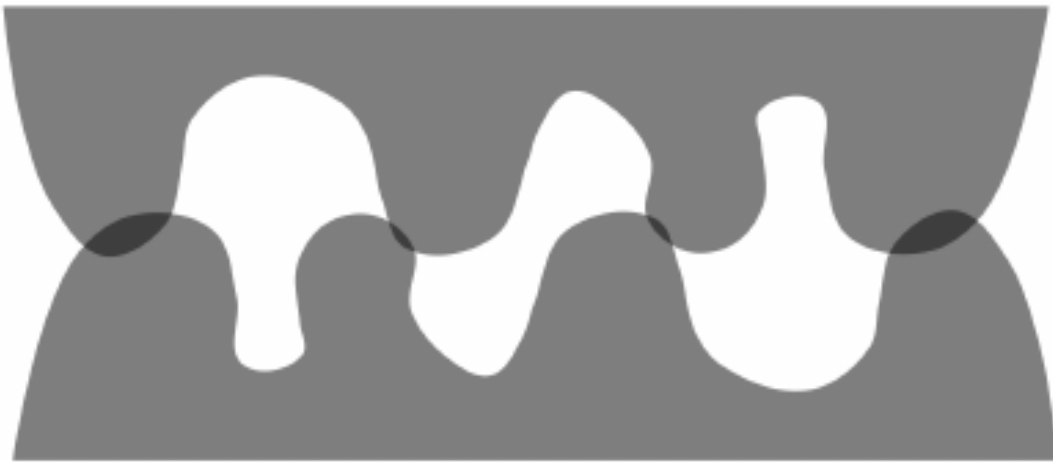
Ballast properties – Particle shape



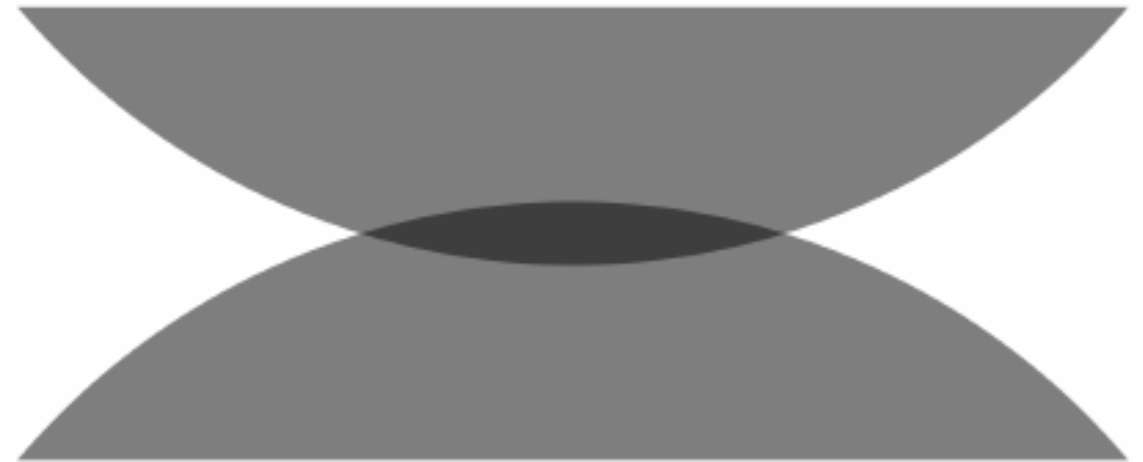
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Ballast properties – Particle stiffness

Hertzian contact model: contact stiffness depends on the contact volume



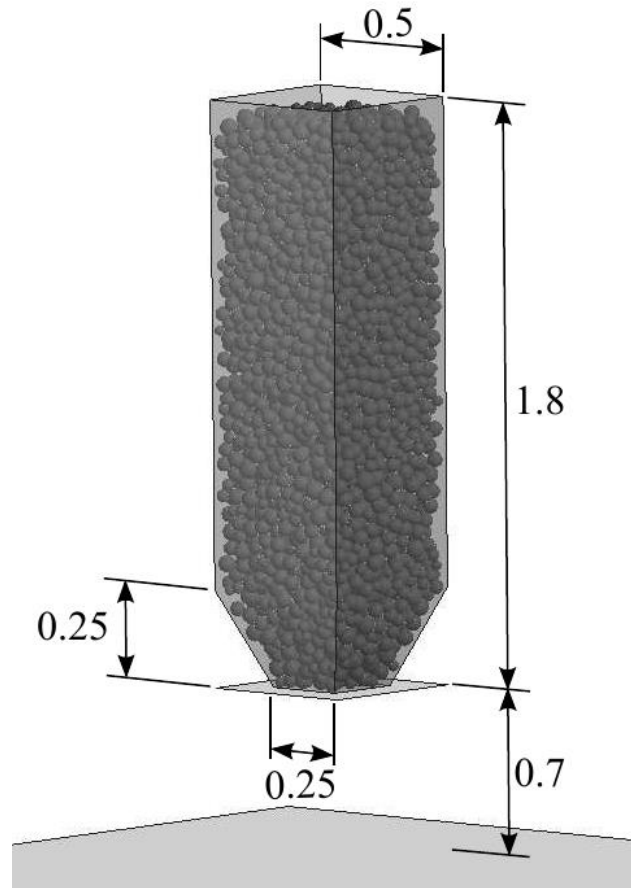
Real contact geometry



Numerical contact geometry

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Repose angle test



Material properties	
Density (kg/m^3)	2700
Poisson coefficient	0.2
Young modulus (GPa)	2.4
Friction coefficient ballast	0.6
Friction coefficient ballast-floor	0.6
Restitution coefficient	0.0
Rolling friction coefficient	0.05/0.1/0.15/0.2/0.25

Repose angle = 40°

Chen, C., McDowell, G. R., & Thom, N. H. (2014). Investigating geogrid-reinforced ballast: Experimental pull-out tests and discrete element modelling. *Soils and Foundations*, 54(1), 1-11.

Repose angle test



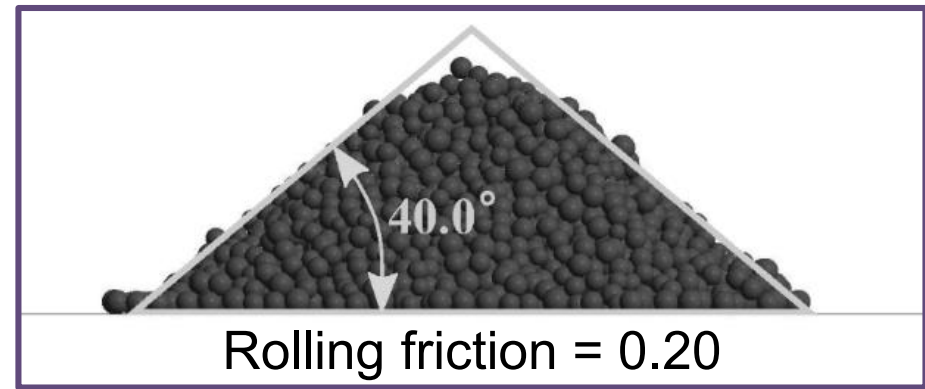
Rolling friction = 0.05



Rolling friction = 0.10



Rolling friction = 0.15

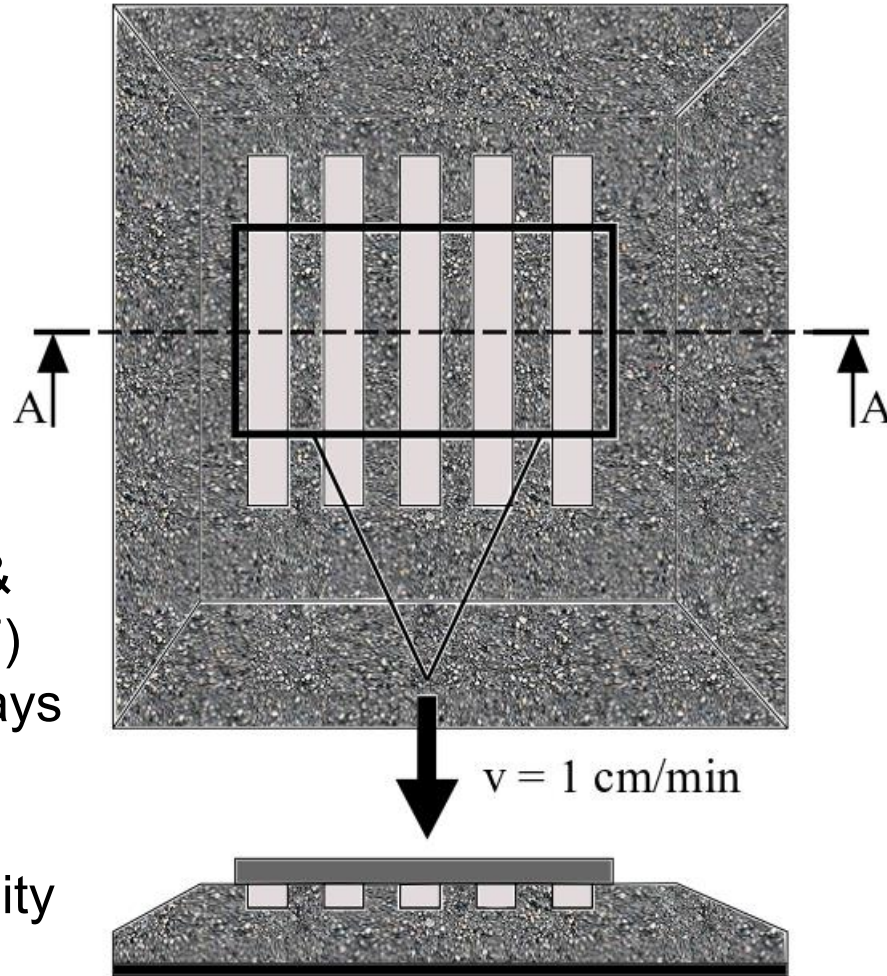


Rolling friction = 0.20

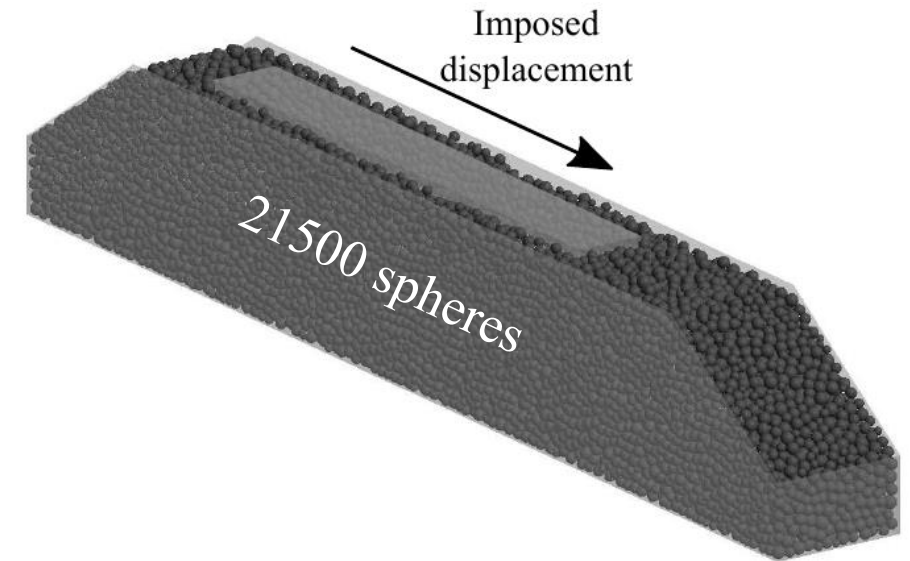
Irazábal, J., Salazar, F., & Oñate, E. (2017). Numerical modelling of granular materials with spherical discrete particles and the bounded rolling friction model. Application to railway ballast. Computers and Geotechnics, 85, 220-229.

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Lateral resistance force test



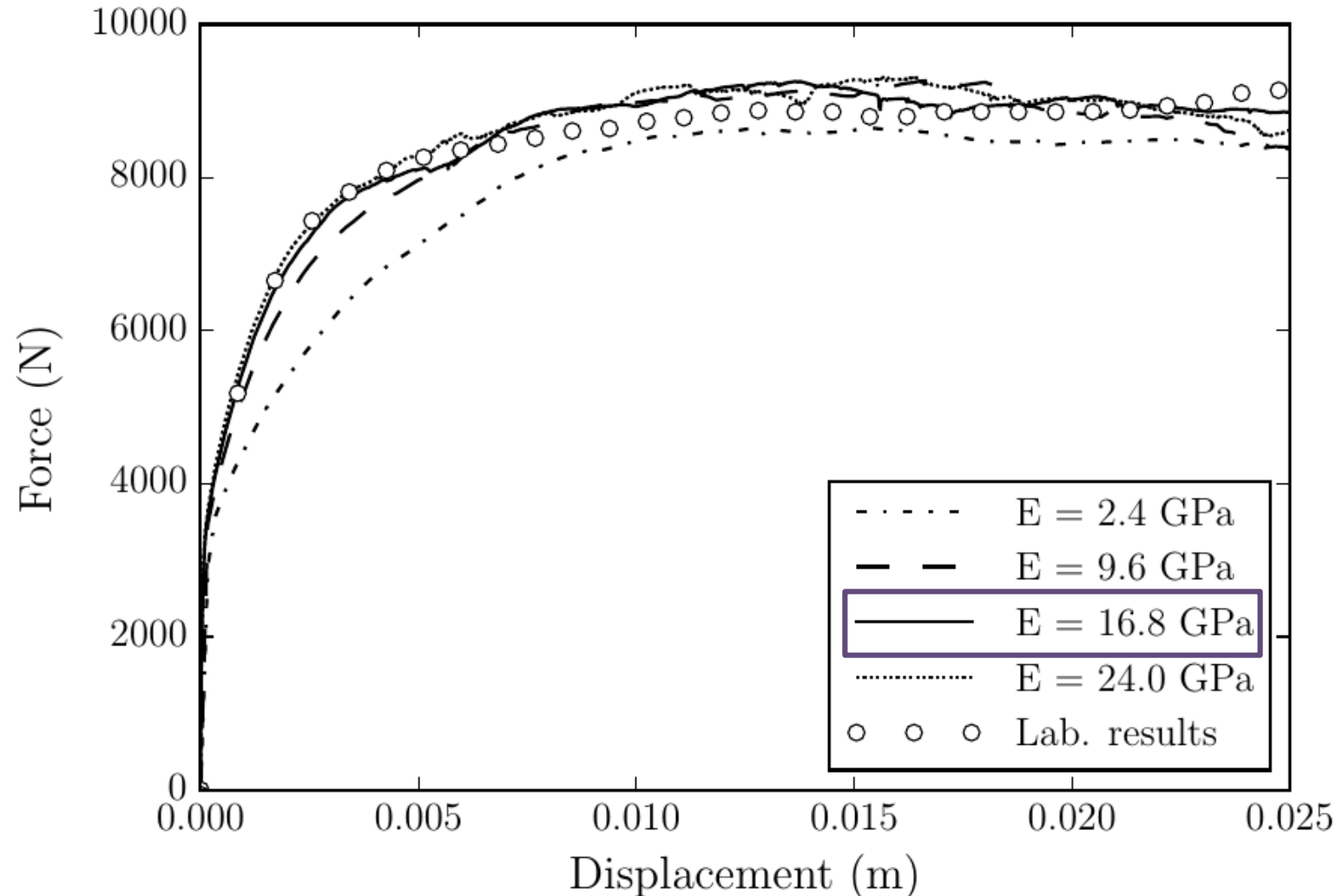
Zand, J. van't, &
 Moraal, J. (1997)
 Roads and Railways
 Research
 Laboratory
 Technical University
 of Delft



Ballast properties	
Density (kg/m^3)	2700
Poisson ratio	0.2
Young modulus (GPa)	2.4/9.6/16.8/24.0
Friction coefficient	0.6
Restitution coefficient	0.0
Rolling friction coefficient	0.2

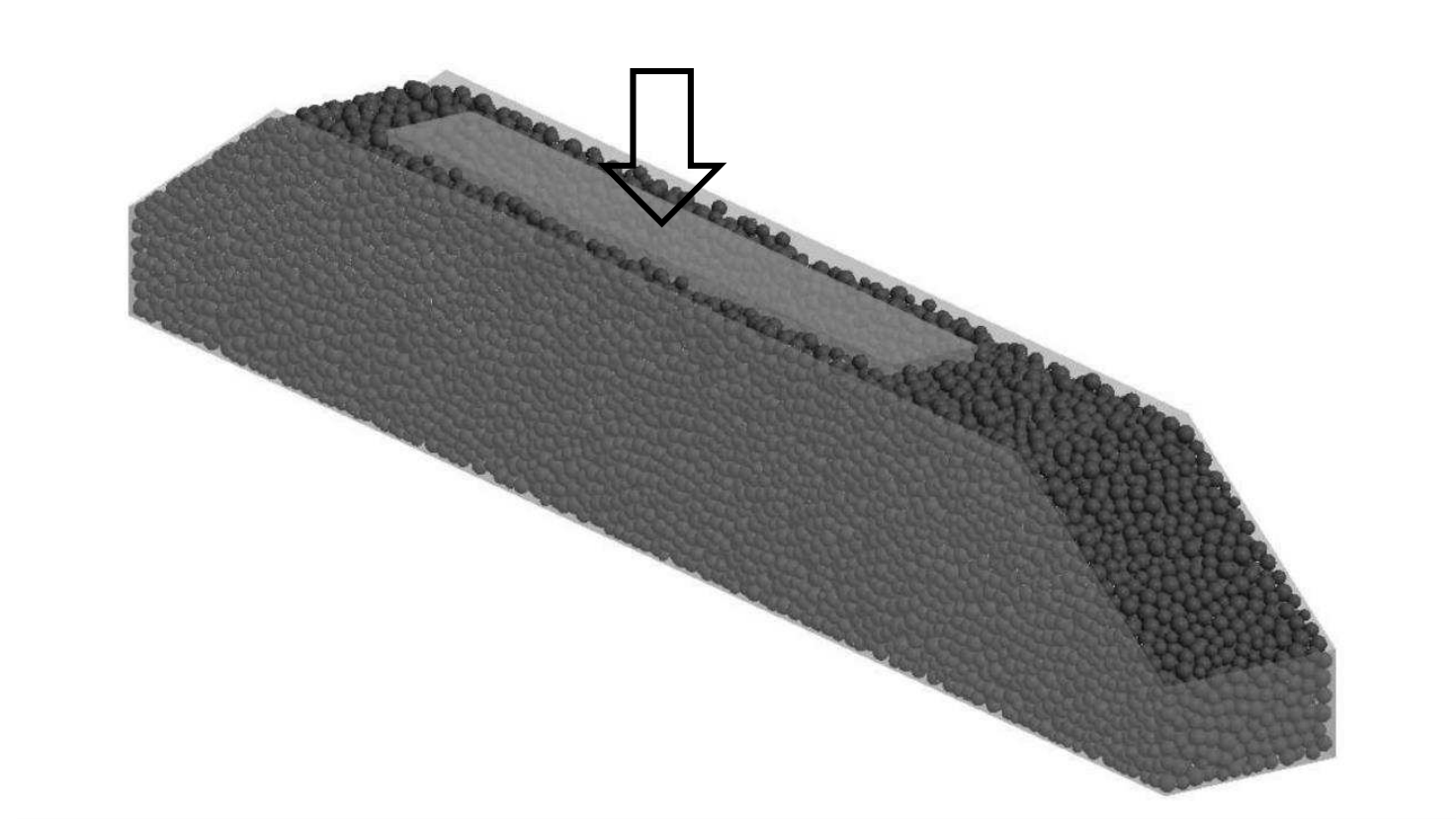
Lateral resistance force test

Irazábal, J., Salazar, F., & Oñate, E. (2017). Numerical modelling of granular materials with spherical discrete particles and the bounded rolling friction model. Application to railway ballast. Computers and Geotechnics, 85, 220-229.



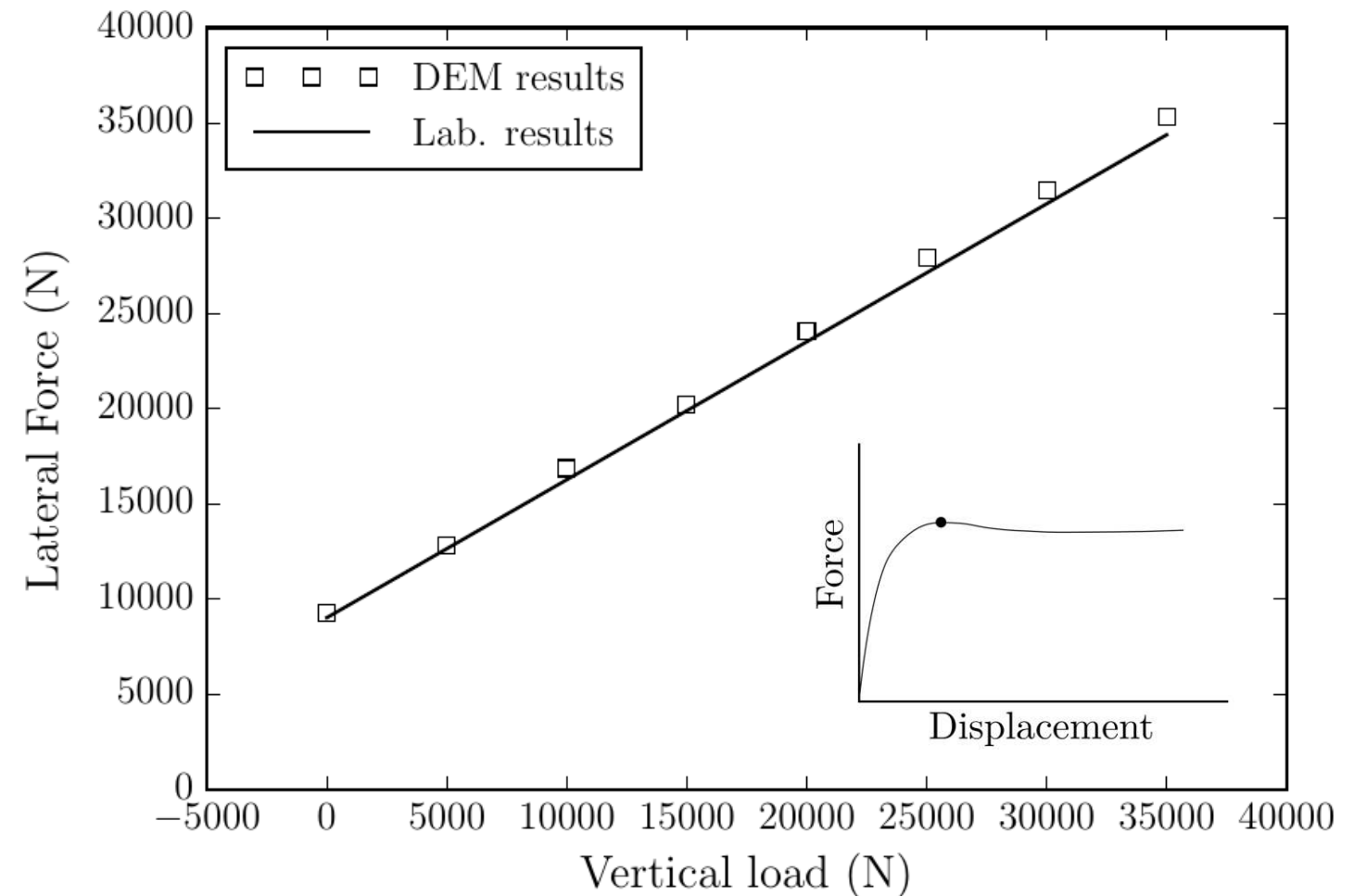
Lateral resistance force test

Vertical load
0 N
5000 N
10000 N
15000 N
20000 N
25000 N
30000 N
35000 N

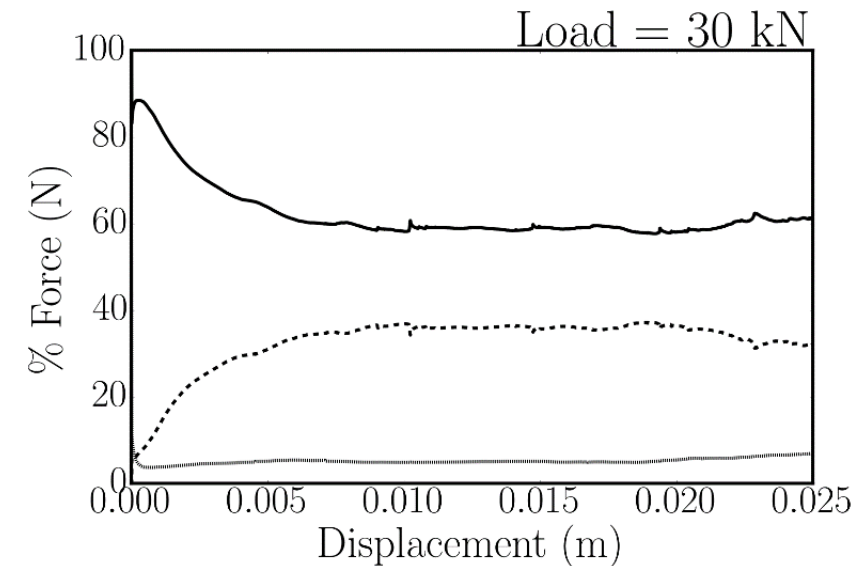
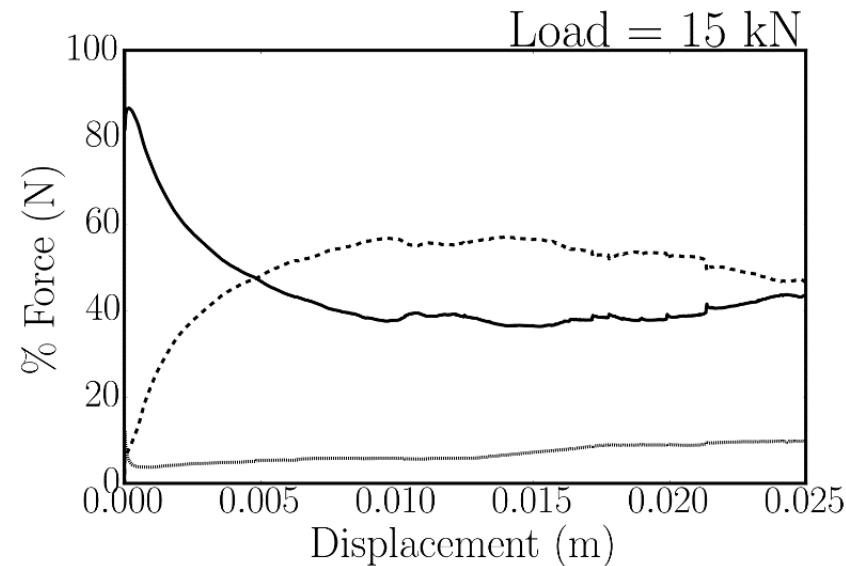
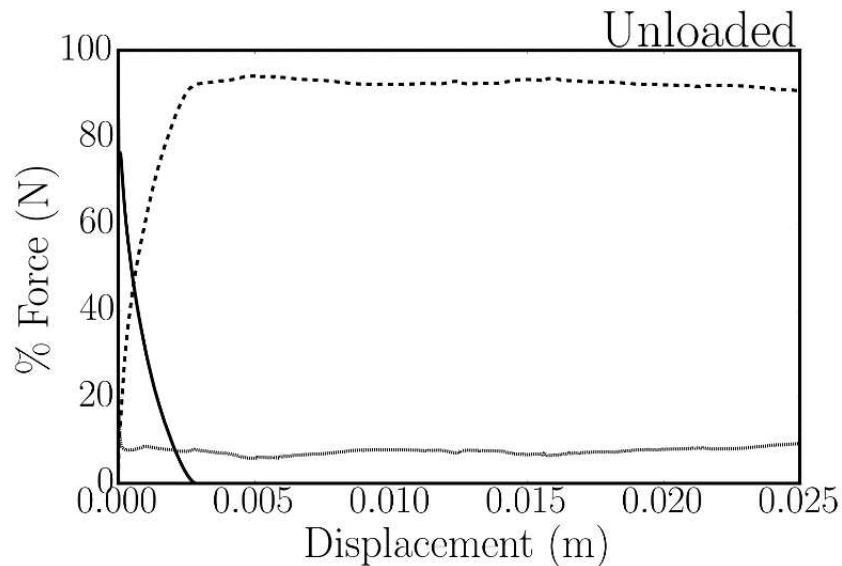
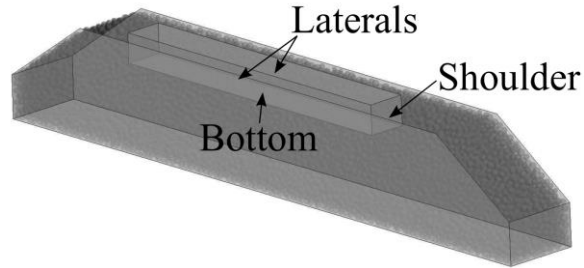
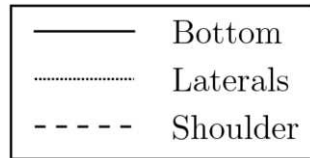


Lateral resistance force test

Irazábal J. Numerical analysis of railway ballast behaviour using the Discrete Element Method. PhD Thesis 2017.

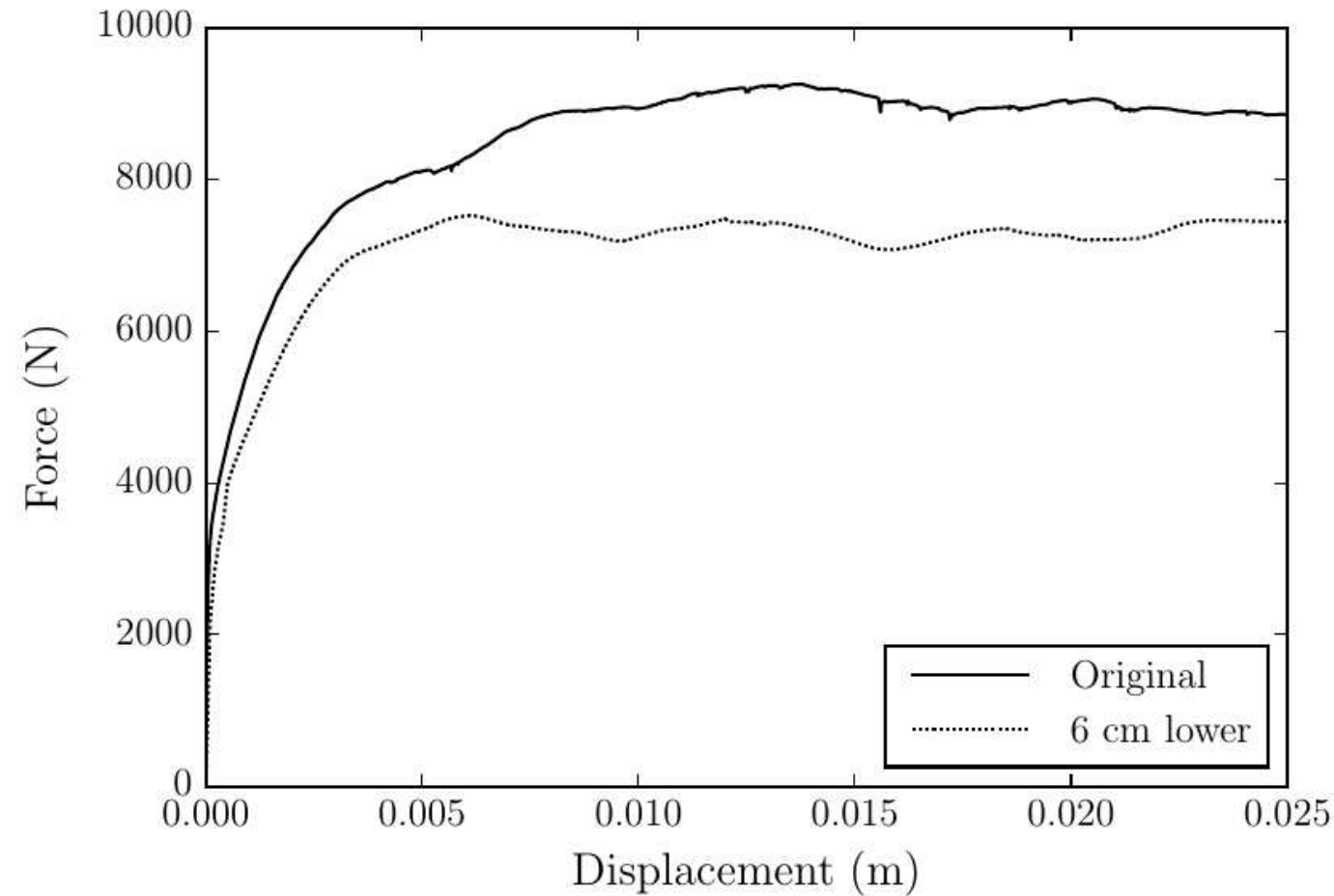
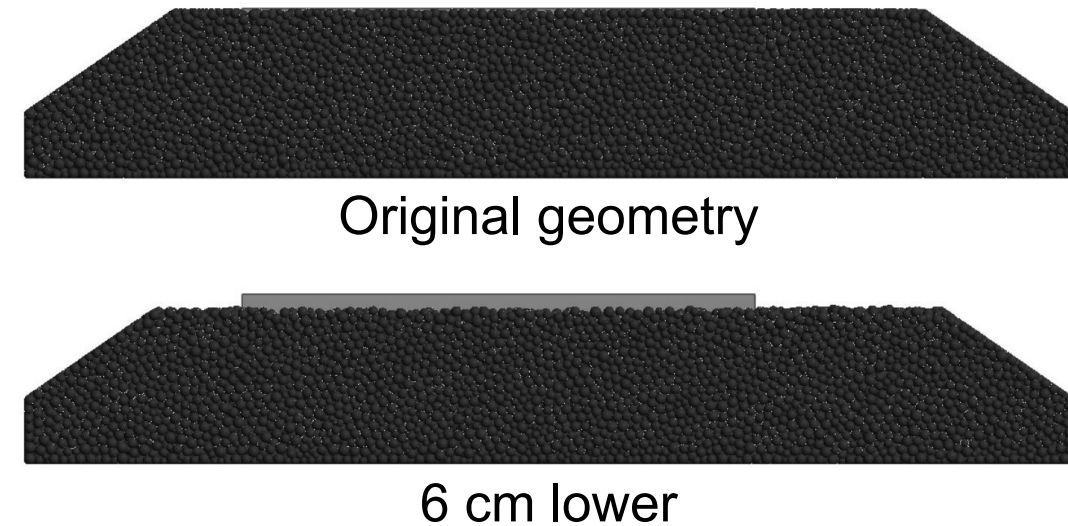


Lateral resistance force test



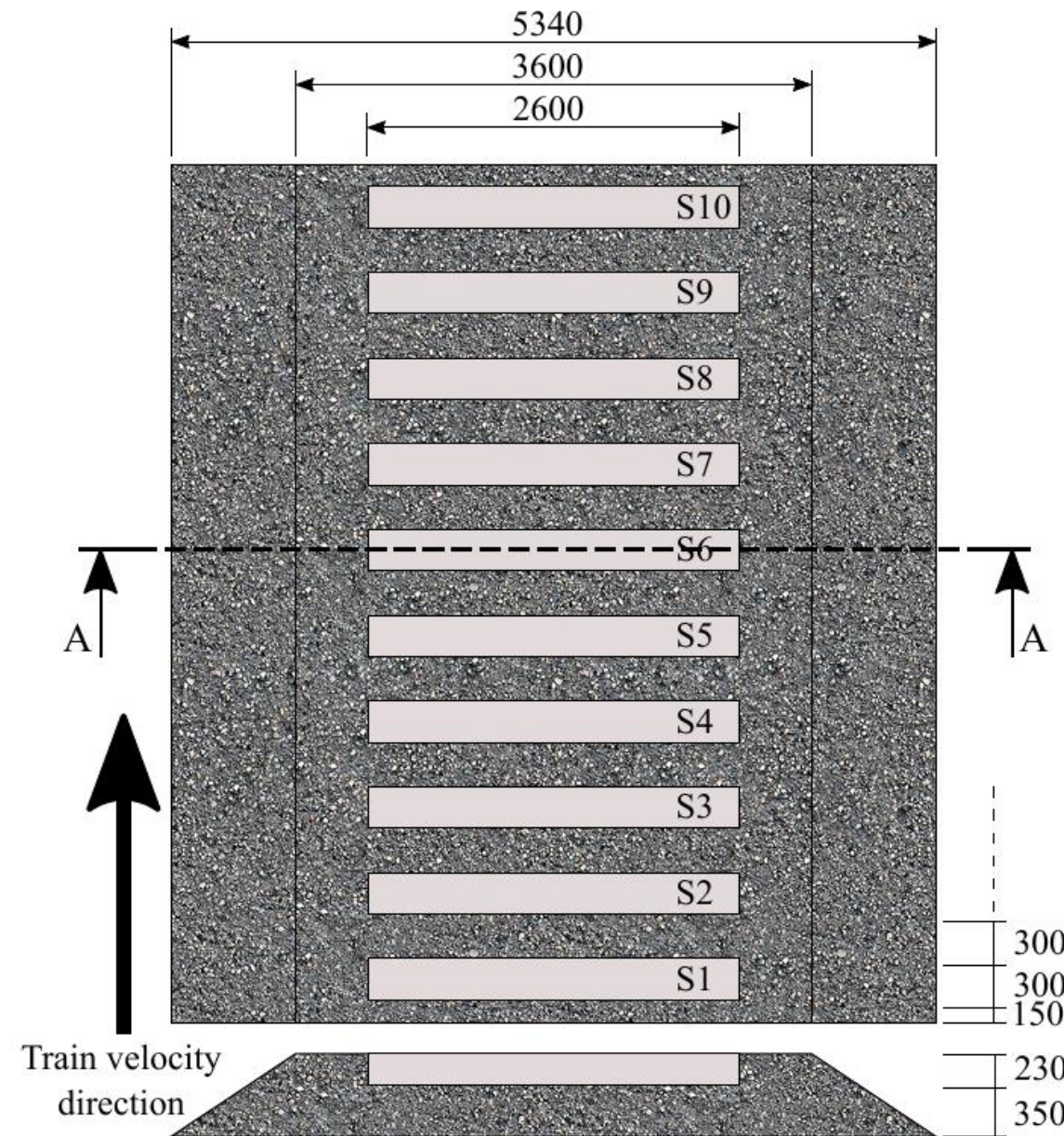
Irazábal J. Numerical analysis of railway ballast behaviour using the Discrete Element Method. PhD Thesis 2017.

Lateral resistance force test



Irazábal J. Numerical analysis of railway ballast behaviour using the Discrete Element Method. PhD Thesis 2017.

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$$Q_S(x, t) = Q \frac{k_{eq}}{K} e^{\frac{-|x-vt|}{L}} \left[\cos \frac{|x-vt|}{L} + \sin \frac{|x-vt|}{L} \right]$$



$Q_s \rightarrow$ load over the sleeper

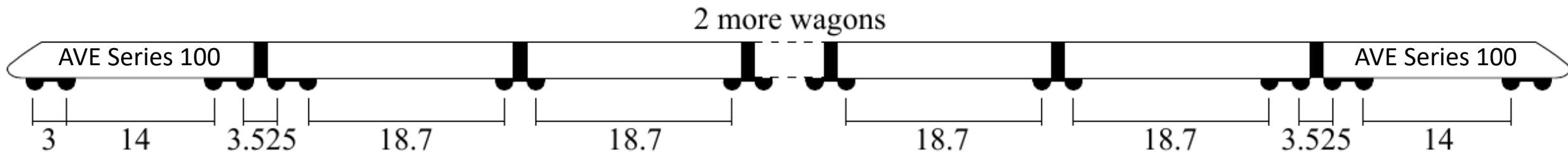
$Q = 168732 \text{ N} \rightarrow$ axle load

$K = 75 \text{ kN/mm} \rightarrow$ track stiffness

$k_{eq} = 33.58 \text{ kN/mm} \rightarrow$ bearing stiffness

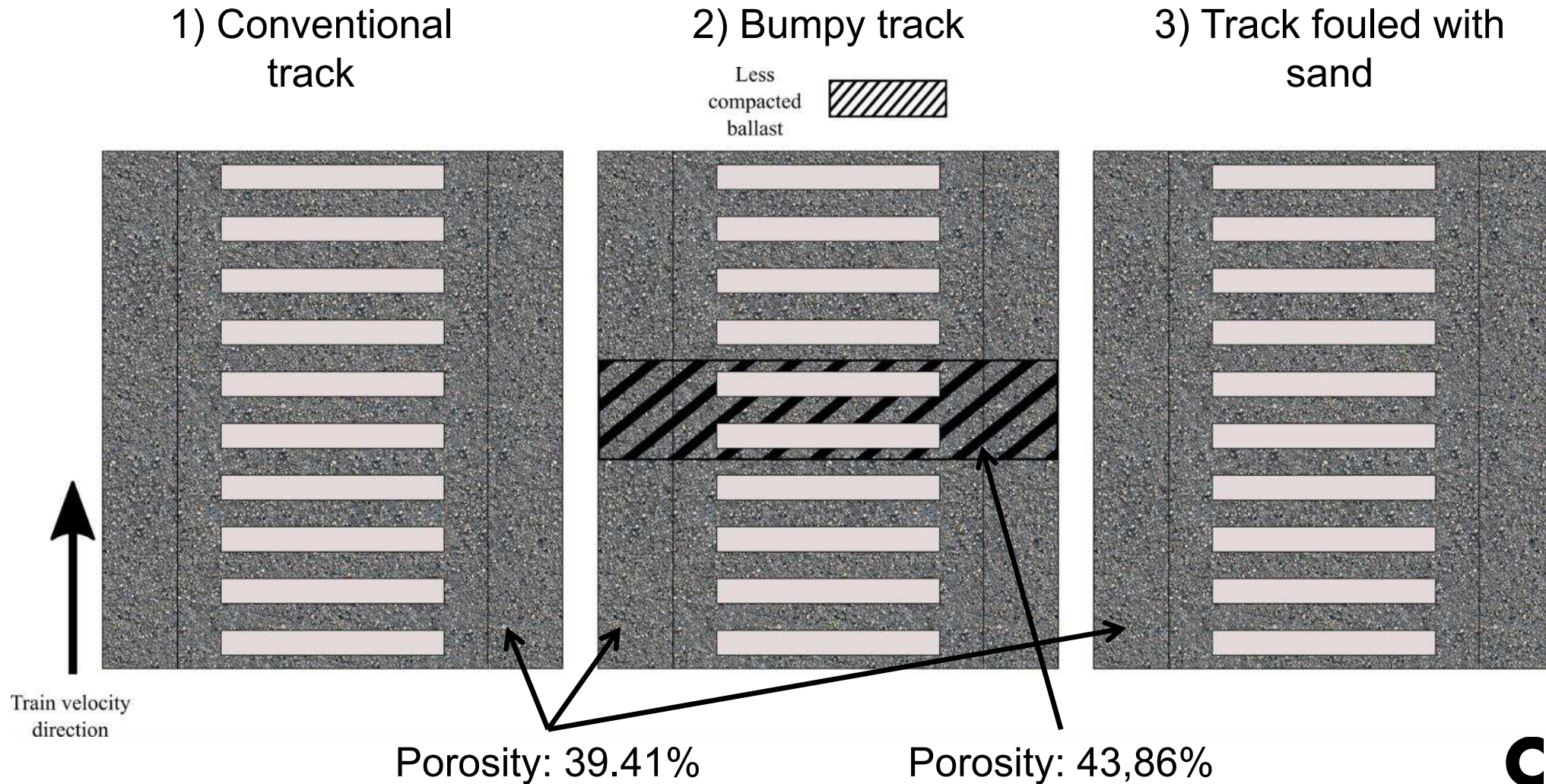
$L = 0.881 \text{ m} \rightarrow$ elastic length

$v = 300 \text{ km/h} \rightarrow$ velocity of the train



Quality evaluation of a railway track subjected to vertical loads

Full scale test



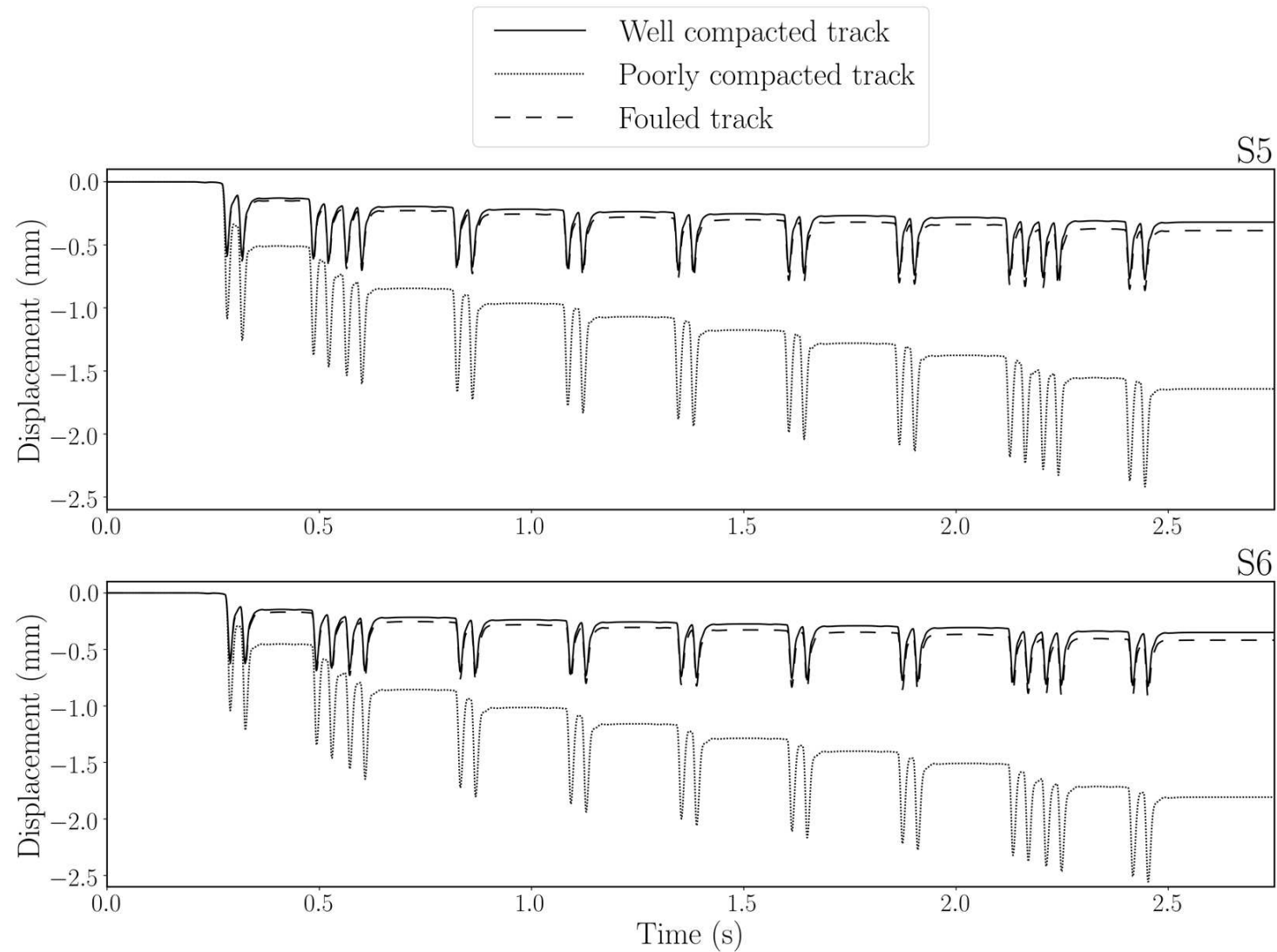
Full scale test – Ballast velocity



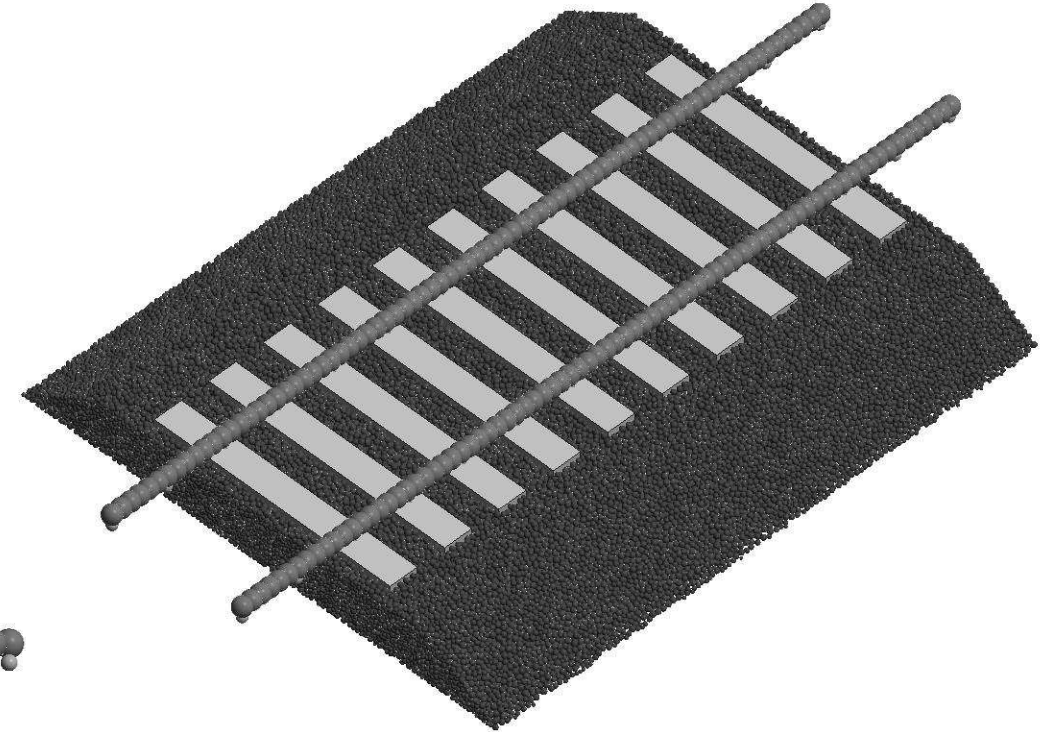
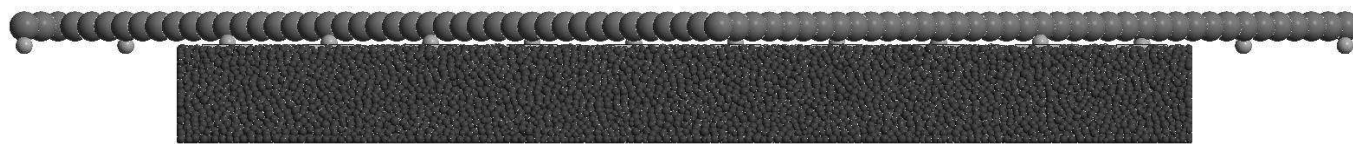
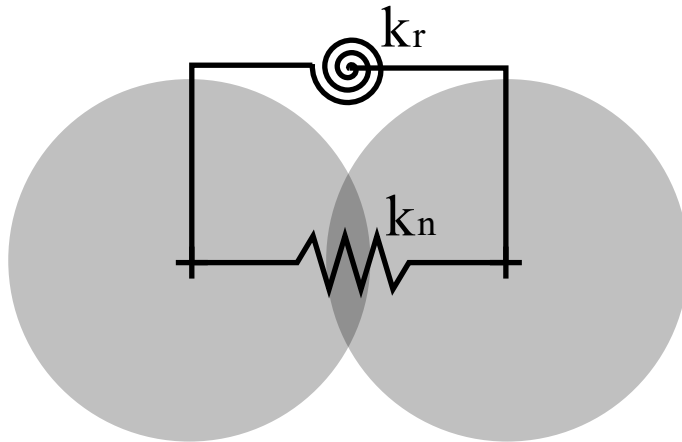
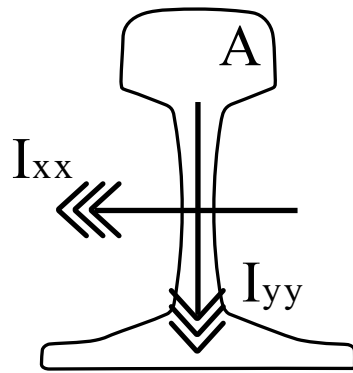
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Full scale test – Sleepers vertical displacement



Full scale test with rails



Numerical representation of rails and bearing plates

Full scale test with rails



$Q = 168732 \text{ N} \rightarrow$ axle load

$A = 77.45 \text{ cm}^2 \rightarrow$ rail cross section

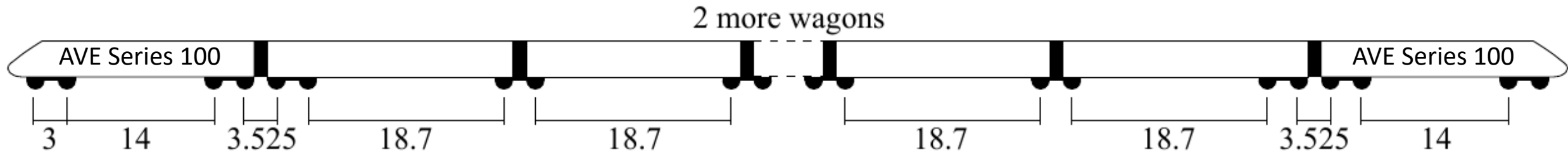
$I_{xx} = 3217 \text{ cm}^4 \rightarrow$ moment of inertia horizontal axis

$I_{yy} = 524 \text{ cm}^4 \rightarrow$ moment of inertia vertical axis

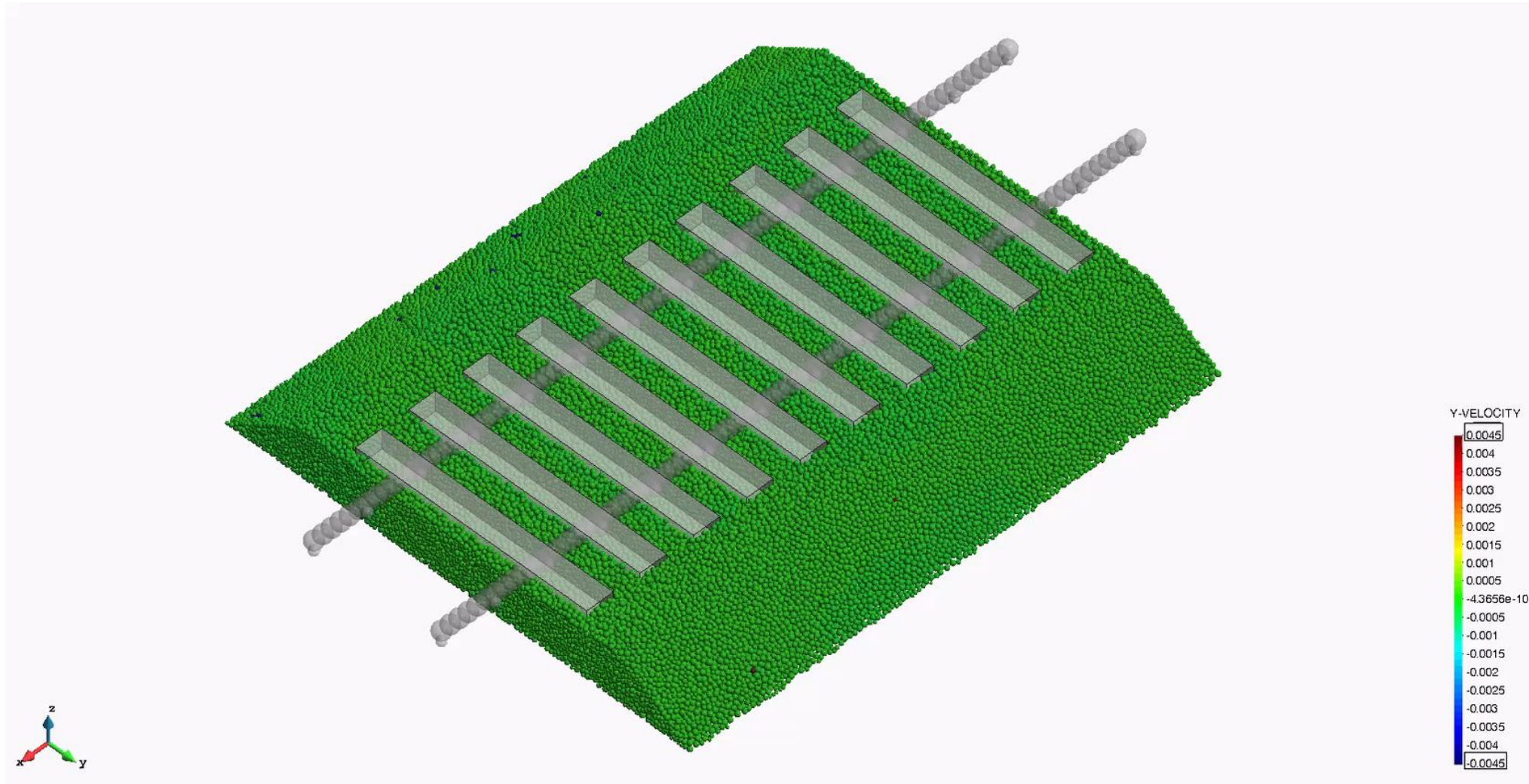
$k_{bq} = 30.75 \text{ kN/mm} \rightarrow$ bearing plate stiffness

$v = 250 \text{ km/h} \rightarrow$ velocity of the train

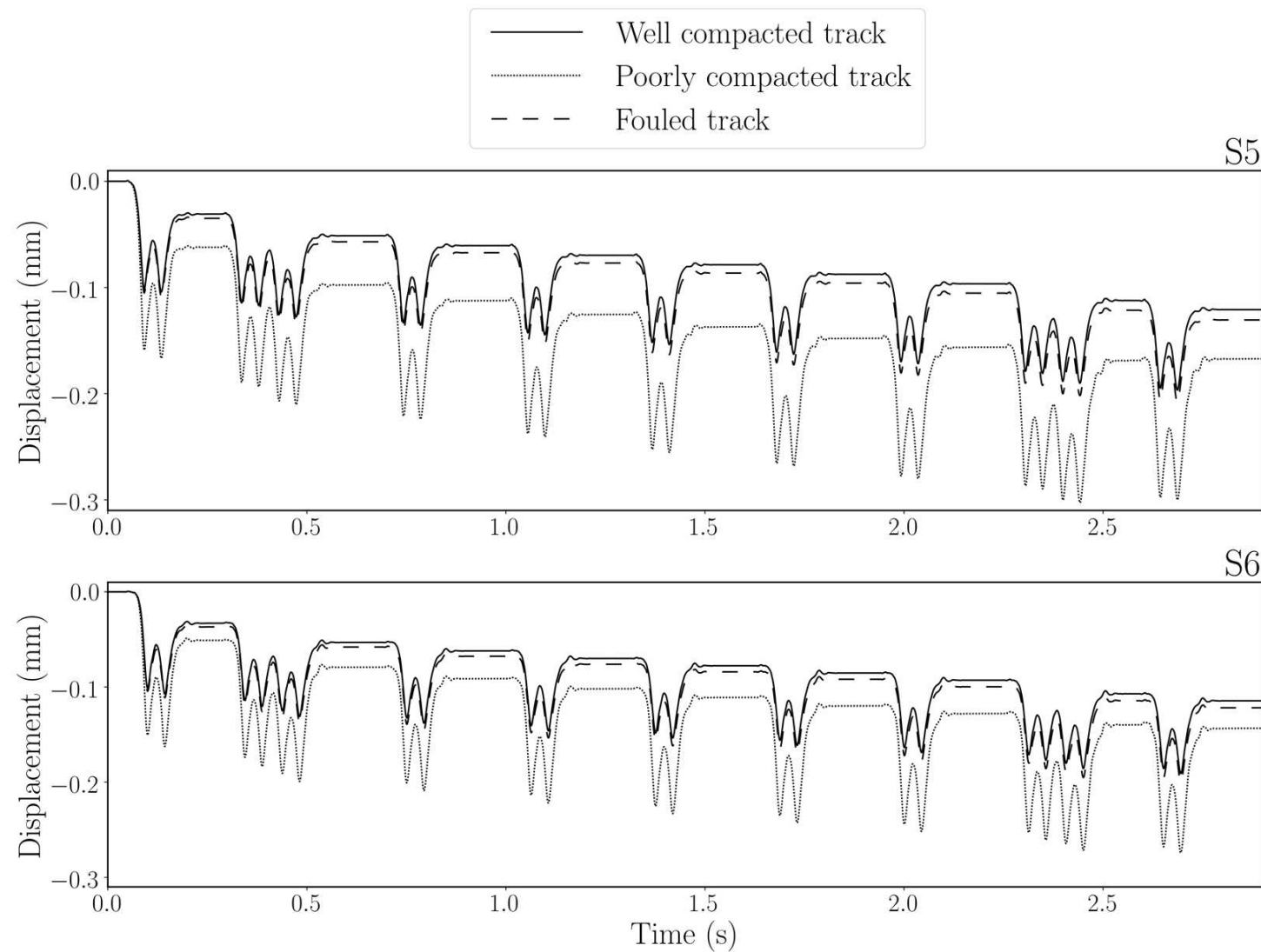
$R = 4000 \text{ m} \rightarrow$ radius of the curve



Full scale test with rails – Ballast lateral velocity



Full scale test with rails – Sleepers lateral displacement



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Conclusions

- The DEM is a valid numerical model for the calculation of ballast behavior
- There is uncertainty in the assignment of properties (mainly shape and stiffness), so calibration is necessary
- Spherical particles are useful if the contacts force and distribution is not a key aspect of the analysis
- The numerical tool presented allows the user to test different situations:
 - Reduction of ballast material
 - Changes in ballast granulometry or properties
 - Improve of sleepers design
 - Changes in sleepers roughness

- Validation of the conditions to introduce ballast fouling
- Calculations with other particle geometries (clusters of spheres) to evaluate wear and fouling
- Improvements in the user interface

Thank you for your attention!